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DISCUSSING MONOTONY IN ATC: EFFECTS OF REPETITIVE TRAFFIC PATTERNS ON PERFORMANCE AND SUBJECTIVE INDICATORS

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This study addresses the concept of monotony in ATC and describes uneventful and repetitive work conditions evoking such a state. Psychophysiological effects of repetitiveness in two simulated ATC-scenarios of low or high dynamic density (DD) were investigated with 24 air traffic controllers (M=29.5 years, 18 male, six female). Interactions approached significance (p<0.1) in conflict resolution time for an out-of-routine conflict situation. Conflict resolution lasted longer in repetitive traffic and resolution time increased from the first to the second run. Those findings are supported by a composite score of subjective attentiveness, fatigue, sleepiness, and concentration with lower values found in repetitive conditions. Although generally decreasing, the switch from low to high DD was rated favorably on the hedonic tone, while tense arousal was reacting more pronounced in non repetitive and low-high condition. In combination with the development of earlier reported cardiovascular (heart rate, heart rate variability) and subjective indicators the results underline the significance of a multidimensional assessment of monotony in ATC.

Introduction

This paper discusses the concept of monotony in air traffic control (ATC) and reports results of an experimental study. Hopkin (1995, p. 341ff.) presents a number of arguments in favor of a more thorough investigation of monotony and boredom in ATC. Amongst these arguments are controllers’ complaints and presumed performance impairments as well as long-term consequences expressed in job satisfaction. Indeed, research has advanced little on that subject within the domain of ATC.

Furthermore, the ambiguous and sometimes unreflected use of terms like monotony, boredom, low vigilance, underload and even fatigue has been addressed by various authors (e.g., Davies, Shackleton & Parasuraman, 1983; Thackray, 1981). This has not yet resulted in a clear distinction and goes beyond the scope of this paper. Nevertheless, it is noted that from a historical point of view apparently different priorities had been set by European and North American researchers resulting in a separate development and domination of theories addressing monotony, boredom or vigilance. The International Standard for mental workload (ISO 10075) recommends handling low vigilance and monotony as independent task attributes. Since the main purpose of the standards is to provide practitioners with guidelines of work design, the offered distinction does not provide a satisfactory theoretical basis.

A comprehensive theory of the concept of monotony included therein was offered by Bartenwerfer (1960, 1985). He stated that monotony is a specific consequence in working situations when continuous engagement in a task is required. Those tasks are of a restrictive nature and may be characterized by low stimulus intensity or variation, high repetition, low difficulty level and longer time on task. As a consequence, physiological deactivation and self-reported feelings like boredom, tiredness or sleepiness are registered. Increased reaction times and reduced ability to readapt after changes characterize performance impairments. This concept seems to be a suitable background for further research in ATC as it stresses the multidimensional effects of predefined task demands. As early as the beginning of the last century, job monotony became a subject of scientific interest, predominantly with the goal to optimize work performance amongst assembly line workers. Another aspect of monotony became relevant when Mackworth (1948) started to study performance of military control personnel to explain failures in signal detection. This contributed to a long tradition of research under the concept of vigilance.
Unfortunately, the long tradition in research on monotony has ignored that totally different task characteristics might lead to complaints about monotony. This was finally considered by Johansson (1989) who distinguished *uneventful* and *repetitive* monotony. Her distinction focuses mainly on control-room operators as an example for uneventful monotony compared to assembly line work representing repetitive monotony. Apparently, in her paper she also adopts the term monotony to describe stimulus conditions. This maintains the unclear classification of monotony as cause and consequence. In contrast, Bartenwerfer (1985) emphasized differentiating objective monotonous working conditions as a cause for an individual state of monotony. Following this statement, the authors prefer to use the term *repetitiveness* (respectively *uneventful* work conditions) to address task characteristics and monotony to indicate the individual response.

Johansson’s distinction facilitates the systematization within the concept as it does not a priori exclude the vigilance concept. However, it has not yet been considered that uneventful and repetitive monotony might occur within one job. Such an example is represented by Air Traffic Control. Rather obviously, uneventful monotony can emerge in situations of low traffic that require few actions. Such a situation varies for regions and centers, but often occurs during night shifts. This aspect has been addressed within vigilance research (e.g., Schroder et al., 1994) with the argument that such monitoring situations mainly demand sustained attention. Nonetheless, results of vigilance research are not directly transferable to ATC. Even in situations of low traffic, a certain complexity is available thus the action cycle includes a variety of steps for task execution. Conversely, errors resulting from both types of monotony might have different reasons. While in uneventful monotony they might occur because of suboptimal activation and consequently slow re-adaptation, in repetitive monotony errors might emerge out of routine that causes omissions in the update of the action cycle. A difference in the psychophysiological monotony pattern need not be shown in either situation.

Few studies have been conducted to better describe monotony in ATC. Thackray et al. (1975) were interested in physiological and subjective changes accompanying monotony and boredom. They found that the group reporting high monotony and boredom showed greater increases in response times, HRV, and strain while attentiveness decreased. In a field study Hoffmann and Lenert (1993) administered a questionnaire with the scope to assess strain reactions in controllers. Increased subjective monotony and fatigue were found towards the end of the shift. Traffic complexity counteracted this effect.

To summarize, there is a need to systematically investigate conditions which cause monotony in ATC considering individual and situational factors. The present study was designed to investigate the role of repetitiveness in simulated ATC. It was hypothesized that physiological and subjective state as well as performance will change due to repetitiveness in traffic characteristics. Furthermore, an influence of traffic complexity was assumed. A simplified version of the dynamic density (DD) concept was introduced (e.g., Laudeman et al., 1998) because it allows an appropriate description of the developing traffic situation over time.

First results from cardiovascular indicators (heart rate, heart rate variability) and subjective ratings have already been reported by Straussberger, Kallus & Schaefer (2004). The repetitive traffic condition resulted in physiological deactivation (decreasing HR, increasing heart rate variability). Mean values in feeling of monotony revealed higher ratings for repetitive scenarios but were interacting with the sequence of Dynamic Density changing from high to low versus low to high.
The present report focuses on performance components and includes subjective ratings.

**Method**

**Participants**

Twenty-four fully qualified air traffic controllers (18 male, six female) of Maastricht Upper Area Control Centre (MUAC) individually volunteered in this study. The session was performed during their planned working schedule. Age ranged from 22 to 47 years (M= 29.5, SD=6.0), on the average they had been fully licensed for six years (SD=5.5) and originated from ten European nations. Participants were randomly assigned to the experimental groups and did not differ in age or professional experience.

**Experimental Design**

**Independent Variables.** The experiment involved a 2 x 2 x 2 x 2 - mixed design. The between-subject-variables comprised repetitiveness (repetitive vs. non repetitive traffic pattern) and sequence of dynamic density (high-low vs. low-high). Each participant completed two scenarios (run 1 vs. run 2), the second within-factor concerned the intervals within runs and was included if repeated measurements were analyzed.

**Dependent variables.** To determine performance during scenarios, conflict resolution times and the number of Short Term Conflict Alert (STCA) events of an out-of-routine conflict situation at the end of the scenario were extracted from simulator log files. They contained information about aircraft position, STCAs and controller actions. The measurement of resolution time started from the appearance of the aircraft in conflict until the first action (change in FL or heading) was undertaken.

Subjective ratings of attentiveness, fatigue (inv.), concentration and sleepiness (inv.) were collected on a 7-point-scale (1=low; 7=high) each 15 minutes until the end of the scenario. After level-corrections those items were summarized in an indicator to reflect how efficient participants felt during performing. Bipolar mood dimensions were assessed with the UWIST Mood Adjective List (UMACL; Matthews et al. 1990) and included tense arousal (anxiety vs. calmness), energetic arousal (vigor vs. tiredness) and hedonic tone (contentment vs. depression).

**Other Variables.** Confounding variables of interest were boredom proneness, action control strategy, initial well-being, initial stress-recovery-state, and personality traits. Control variables also comprised biographic data. Further effects of an introduced countermeasure and additional physiological measures (EEG, EOG, and EDA) will be reported separately. A detailed description of cardiovascular and subjective measures (further ratings included strain, boredom and irritation, feeling of monotony, NASA-TLX) can be found in Straussberger et al. (2004).

**Procedure**

A separate simulation room was allocated for the study on the premises of MUAC. Participants were allocated either to the morning session at 8:00 or to the afternoon session at 14:00, counterbalanced for experimental conditions. Before participating in the session, they were provided with information and signed a consent form. An average session lasted 5.25 hours. The experimental session started with 90 minutes of briefing, preparation for physiological recordings and set-up familiarization. After 15 minutes of rest break, two traffic scenarios of 45 minutes each were run. The introduction of the countermeasure required the completion of a short third run. Physiological recordings were collected with a Vitaport III recorder (Temec Inc.) throughout the session, including several baselines at the beginning and end of the scenarios. Subjective ratings were collected during the traffic scenarios. UMACL and other questionnaires were administered subsequently. Participants were video-taped during scenarios and a debriefing concluded the session.

**Task**

Participants worked on a simulated controller working position (CWP) including a 28” LCD monitor with keyboard and mouse for inputs; STCA was available and Reduced Vertical Separation Minimum (RVSM) for Europe applicable. The simulation environment involved a semi-generic upper airspace (FL 250 – FL600) created for this experiment that was implemented as a standalone sector with two automatic feed sectors (no pseudo-pilots). The sector involved arriving and departing traffic from a major airport.

Four traffic scenarios with medium traffic load (57 aircraft per hour) were created according to the experimental manipulations. Regularly occurring potential conflicts would result in a very close near-miss in three-minute-intervals if the controller did not take appropriate action.
In repetitive scenarios, participants were presented with potential conflicts occurring at the same crossing point. This situation consisted of an aircraft in departure meeting an incoming northbound aircraft after two minutes in the sector. The non repetitive scenarios contained potential conflicts at varying crossing points throughout the sector. In order to obtain a task-performance-indicator, an out-of-routine conflict situation was introduced in the last interval of the scenario.

For the manipulation of DD, major factors such as number of aircraft, number of level changes, routes, and crossing points remained constant in three-minute-intervals throughout the scenario. The manipulation between high and low DD was implemented with additionally required level changes.

Controllers were instructed to control traffic as usual; a deviation concerned keeping aircraft on the planned route without redirecting.

**Results**

Statistical analysis employed a repeated measure ANOVA with repetitiveness and sequence of DD as between factors, and run and intervals within run as within factors. An alpha level of .05 was used for statistical tests. Differences in course and effects of DD were determined from trend analysis. It is noted that any significant interactions between sequence of DD and run express effects of counterbalancing.

**Table 1.** Mean conflict resolution time (SD) for repetitive and non repetitive traffic and l-h vs. h-l sequence of DD with n=23

<table>
<thead>
<tr>
<th>Repetitiveness</th>
<th>Low DD</th>
<th>High DD</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>l-h</td>
<td>h-l</td>
<td></td>
</tr>
<tr>
<td>Run 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>l-h</td>
<td>h-l</td>
<td></td>
</tr>
<tr>
<td></td>
<td>279.83 (141.78)</td>
<td>287.17 (104.30)</td>
<td>294.83 (41.35)</td>
</tr>
<tr>
<td></td>
<td>301.83 (129.39)</td>
<td>305.00 (66.40)</td>
<td>280.33 (110.46)</td>
</tr>
</tbody>
</table>

Table 1 displays mean and standard deviation of conflict resolution time. One subject was excluded from analysis as conflict resolution time could not be determined in one run. ANOVA did not reveal significant differences for the main factors.

There is a tendencially significant increase in conflict resolution time from the first to the second run (F1=3.69, p=.070). Interactions between run and sequence of DD (F1=3.12, p=.093) and between run, sequence of DD and repetitiveness (F1=3.43, p=.080) are approaching significance and depicted in Figure 1.

**Table 2.** Frequency of STCA events (STCA/ No STCA) for out-of-routine conflict situation (n=24, 2 Scenarios)

<table>
<thead>
<tr>
<th></th>
<th>Low DD</th>
<th>High DD</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repetitive traffic</td>
<td>3/9</td>
<td>3/9</td>
<td>6/18</td>
</tr>
<tr>
<td>Non repetitive traffic</td>
<td>0/12</td>
<td>2/10</td>
<td>2/22</td>
</tr>
<tr>
<td>Total</td>
<td>3/21</td>
<td>5/19</td>
<td>8/40</td>
</tr>
</tbody>
</table>

The frequency of STCA (Table 2) that occurred in the out-of-routine conflict situation represented a very rare event. For this reason, the factor run was excluded from analysis and DD (low vs. high) treated as between subjects variable. The Exact Fisher Test was run separately for each factor to examine the distributions of STCA events compared to no STCA events and resulted in no significant difference for either variable.

**Figure 1.** Conflict resolution time in the first and second run depending on repetitiveness and dynamic density

The indicator for subjectively reported feelings of efficiency revealed a main effect of repetitiveness (F1=9.80, p=.005), with lower ratings during repetitive traffic. An overall decrease occurred from the first to the second run (F1=23.16, p=.000) and within one scenario (F2=37.31, p=.000). Significant interactions were found between interval and repetitiveness (F2=6.76, p=.003, linear F1=13.03, p=.002). A significant interaction between run, interval and repetitiveness is depicted in Figure 2 (F2=5.49, p=.008; linear F1=1.97, p=.012). Also the interaction between repetitiveness, sequence of DD, run, and interval resulted in significance (F2=4.01, p=.026; linear F1=5.51, p=.019).
Subjective mood was assessed on three dimensions (Table 3). On the subscale hedonic tone a significant main effect of sequence of DD was found. Participants rated their hedonic tone significantly higher \((F_{1}=6.68, p=.017)\) when they executed the scenarios in the order from low to high DD, but a general decrease from the first to the second run was found \((F_{1}=6.93, p=.016)\).

Table 3. Average ratings (SD) for mood dimensions \((HT=\text{hedonic tone},\ TA=\text{tense arousal},\ EA=\text{energetic arousal})\) depending on repetitiveness \((\text{repetitive vs. non repetitive traffic})\) and sequence of DD \((h-l \text{ vs. } l-h)\) for \(n=24\)

<table>
<thead>
<tr>
<th></th>
<th>Repetitiveness</th>
<th>Repetitive</th>
<th>Non repetitive</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Repetitive l-h</td>
<td>h-l</td>
<td>l-h</td>
</tr>
<tr>
<td>HT Run 1</td>
<td>2.94</td>
<td>2.81</td>
<td>2.94</td>
</tr>
<tr>
<td></td>
<td>(.32)</td>
<td>(.21)</td>
<td>(.32)</td>
</tr>
<tr>
<td>Run 2</td>
<td>2.79</td>
<td>2.60</td>
<td>2.89</td>
</tr>
<tr>
<td></td>
<td>(.19)</td>
<td>(.18)</td>
<td>(.20)</td>
</tr>
<tr>
<td>TA Run 1</td>
<td>2.92</td>
<td>2.90</td>
<td>2.56</td>
</tr>
<tr>
<td></td>
<td>(.19)</td>
<td>(.18)</td>
<td>(.38)</td>
</tr>
<tr>
<td>Run 2</td>
<td>2.98</td>
<td>2.73</td>
<td>2.69</td>
</tr>
<tr>
<td></td>
<td>(.22)</td>
<td>(.18)</td>
<td>(.30)</td>
</tr>
<tr>
<td>EA Run 1</td>
<td>1.56</td>
<td>1.67</td>
<td>1.73</td>
</tr>
<tr>
<td></td>
<td>(.17)</td>
<td>(.19)</td>
<td>(.48)</td>
</tr>
<tr>
<td>Run 2</td>
<td>1.63</td>
<td>1.44</td>
<td>1.75</td>
</tr>
<tr>
<td></td>
<td>(.24)</td>
<td>(.10)</td>
<td>(.14)</td>
</tr>
</tbody>
</table>

Tense arousal revealed significant interactions between repetitiveness and sequence of DD \((F_{1}=6.39, p=.020)\), between repetitiveness and run \((F_{1}=5.83, p=.025)\) and sequence of DD and run \((F_{1}=4.38, p=.049)\). In the conditions of non repetitive traffic respectively low-high sequence of DD tense arousal increased from the first to the second run.

Average values were generally higher for repetitive and high-low condition, a slight decrease occurred from the first to the second run. No significant differences emerged on the energetic arousal subscale.

**Discussion**

The importance of monotony has been underestimated in ATC and this subject has not yet been well researched. The present study attempts to contribute towards filling this gap. In the introduction we outlined that it is important to consider both uneventful and repetitive work conditions as potential causes of a state of monotony. We focused on the latter and investigated it in simulated ATC. The reported results on performance and the subjective dimension complement those of physiological and other indicators described in Straussberger et al. (2004). In our previous work the physiological deactivation pattern was found in cardiovascular indicators and accompanied by increased ratings of feeling of monotony in repetitive traffic conditions. The current analyses support the results as subjectively perceived impairments were found in an indicator summarizing attentiveness, concentration, fatigue, and sleepiness.

But the multidimensional assessment of a state of monotony as proposed by Bartenwerfer also considers impairments on the performance level. For this reason, the conflict resolution time and frequency of STCA events in an out-of-routine conflict situation where studied. We found that conflict resolution time increased from the first to the second run and was longer in repetitive conditions. Although statistically not significant, the distributions of STCAs complete this picture. Low mean values found in the group that performed the first run in non repetitive high DD conditions are not caused by individual outliers. Furthermore, the values in the repetitive traffic condition demonstrate a wider range.

The decrease in hedonic tone expresses that the traffic density and its sequence affect the controllers’ well-being. Even though descriptive values indicated decreases in repetitive conditions on energetic arousal, its insignificant result might have been influenced by manipulations in DD to result.

To a certain extend, the results can be compared to those of Thackray et al. (1975), as they found a similar cardiovascular pattern for the group with high ratings in feeling of monotony and boredom. Also, they rated their attentiveness lower and showed performance impairments. While their interpretation focused on reduced attention, we prefer to explain the...
results with a general impairment in the individual state. An advantage of the present study is that the sample consists of air traffic controllers and the simulation environment offered a better representation of reality.

The data also indicate that monotony develops rather soon, whereas after a longer time-on-task general fatigue overlaps with consequences of repetitiveness.

Nonetheless it is surprising that a state of monotony can result in ATC as a probable consequence of repetitive traffic conditions, especially since up to date research focused predominantly on situations of stress and vigilance.

Conclusion and Outlook

Future analysis will address the influence of confounding variables and result in recommendations concerning work organization and selection of controllers. Nevertheless it should be kept in mind, that further studies in the field will be necessary to better understand the origin of these phenomena.

It is critical that developments in ATC do not ignore research on monotony. This is especially true due on the one hand to an ongoing trend towards automation, and on the other hand in consideration of controllers handling increasingly complex traffic in the future. In both cases, the role of monotony needs to be clearly addressed and understood, as it is implicitly included in many attempts to cope with predicted traffic increases.

References


**Acknowledgements**

The PhD study of Sonja Straussberger is funded by Eurocontrol Experimental Centre in Brétigny sur Orge, France.